Integration of Building Envelope and Services via Control Technologies

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Abstract: - The last decade offered the foundation of several seminal concepts, which although natively composite and complex, amply demonstrate the potential of 21st century technology to affect important societal trends. Among notable candidates, the convergence of technologies related to information and energy, has revealed the potential to reform conventional modes of operation towards a sustainable and more rational way of resources utilization. Perhaps the most profound example of this technological integration will be met in forthcoming planning of residential and industrial building design, where the rapid advance of co-generation technologies and respective legislation follow-up, pave the way for a vast growing market. The rational behind this blooming market becomes directly apparent, considering that the international power authorities and vendors, must —among many other issues such as power network safety- urgently address the gross imbalance between central power generation (93% global share), which is characterised by high losses from transmission and distribution (T&D) systems and inefficient power plants. Electricity losses are running at a minimum of 13.4% a year from developing countries T&D systems, while the efficiency of central power plants is only around 33%. This waste of energy, which is directly associated with the traditional model of central power generation -but can be largely stopped by the use of building-level cogeneration, is dragging along massive social, economic and environmental damage -particularly to the world's poor countries. Millions of people are failing to receive a supply of electricity as a consequence; national fuel bills are billions of dollars higher than they could be, and pollutant emissions are causing untold additional health and environmental harm. At this point it must be clearly stated, that at the context of this paper the term services is restrained to energy consumption reduction services.

1　　Introduction

The integration of building envelope and services via control technologies is an essential part of an intelligent building. The concept of an intelligent building is, and will probably remain, ill-defined. In its most general sense it should mean a building that in some way can sense its environment, reach decisions about the state of that environment and communicate those decisions. In practice this should mean that a building can adjust some aspect of the interior or exterior environment in response to a change in some other aspect of that environment.

The external envelopes of buildings are a critical element of energy design, determining the level of protection against outdoor conditions and also controlling the indoor environment. An integration scheme of building envelopes and services via control technologies is examined in this paper. More precisely, it will be presented a systemic approach for a controlling scheme applied to the problem of controlling automatically openings of the building, allowing better natural circulation of the air in the building (between the two facades and in the main part of

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the building) and hence provoking drastic reduction of heating, ventilation and air - conditioning loads of the building.

A paper, already accepted for publication [1], describes the design and control methods for many aspects of energy consumption in a building, mainly lighting and heating / cooling, using the EIB / KONNEX technology. The basic objective is to present a modularly expandable and generally adaptable technology in order to progress from the stage of individually designed systems towards to wide range reliable integrated systems. It is shown that this technology provides the most reliable solution for controlling such systems, because of its standardization. Supervisory control and energy management of an intelligent building using EIB – KONNEX technology can be sent by the exploitation of EIB Power Line Communication. The paper is based on previous works, mainly summarized in [2], [3], [4], [5] and [6].

2   EIB – KONNEX Technology

EIB is an innovative building installation technology ("bus system") which has been promoted since 1990 by the EIBA group of manufacturers (EIB association) which has its headquarters in Brussels. EIBA is involved with issuing trademarks, testing and quality standards, standardization and marketing activities.

The flexibility and modularity of European Installation Bus (EIB / KONNEX) technology using twisted pairs, power lines and radio frequency media in combination with the availability of compatible components by a growing number of large manufactures are some of its major assets.

Various methods have been developed in facing the traffic congestion in domestic networks so far. However, all these methods can be applied through the EIB / KONNEX technology. Especially, compatibility is achieved by using EIB / KONNEX standard interfaces. The advantages of this solution are high reliability, simple expandability as well as simple installation, use and maintenance.

Furthermore, exploiting the communication via power lines, a low cost energy management for lightning can be integrated in it, achieving significant energy saving by using dimming scenarios at certain time periods.

The advantages of EIB are:

1.   Increased safety,
2.   Economic use of energy during the operation of buildings
3.   Simple adaptation of the electrical installation to the changing requirements of the user
4.   Higher degree of convenience

The above arguments are evaluated differently from the point of view of the client or the user of the installation e.g. office building compared to residential building, able-bodied people compared to disabled people, young people compared to elderly people

Devices from different manufacturers and functional areas that are supplied with the EIB trademark can easily be linked to form a functioning EIB installation.
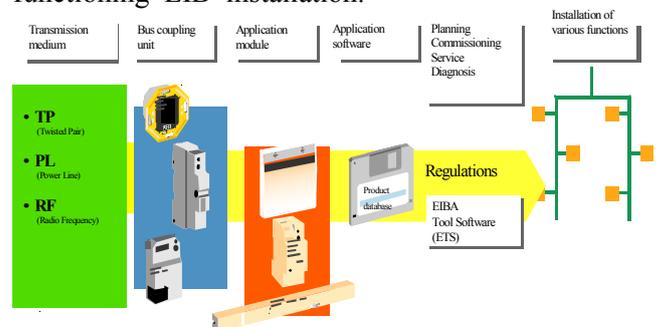
Figure 1: The EIB (bus system) architecture.

EIB installations can easily be looked after by any trained EIB installer as there is only one uniform, PC-based project design and maintenance tool called ETS (EIB Tool Software). This tool does not require any programming knowledge. Any installer/planner who has been trained in accordance with EIBA guidelines can use the EIB partner logo and is held on a list. The Success Rate is:

-       more than 4,000 registered and certified EIB products
-       more than 100 EIBA members
-       more than 70 recognised training schools
-       more than 6 European test sites
-       more than 10,000 implemented projects
-       more than 10 million installed EIB products (as at middle of 2000).

3.2   Communication
3.2.1 Basic Method of Operation

A minimum TP EIB installation consists of the following components:

•   a power supply unit (24V DC),

- a choke (can also be integrated in the power supply unit),
- sensors (a single switch sensor is represented in the graphic above),
- actuators (a single switch actuator is represented in the graphic above) and
- a bus cable (only twin core is required).
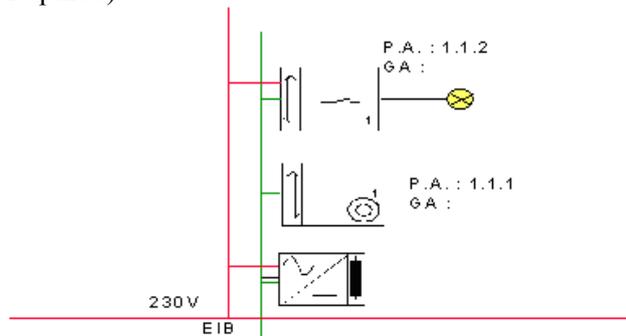
Figure 2: A minimum TP EIB installation.

After the installation, an EIB system is not ready for operation until sensors and actuators have been loaded with application software with the help of the ETS program. The project engineer must however first have carried out the following configuration steps using ETS:

- assignment of physical addresses (for the unique identification of a sensor or actuator in an EIB installation);
- selection and setting (parameterisation) of the appropriate application software for sensors and actuators;
- assignment of group addresses (for linking the functions of sensors and actuators).

3.2.2   Useful Data Telegram

In principle a distinction is made in the data between the commands.

The data is shown here using the example of a 1-bit telegram. In the case of the "write" command the last bit on the right contains a "1" or a "0" for "Switch on" or "Switch off". The "read" command requests the addressed bus device to report its status.
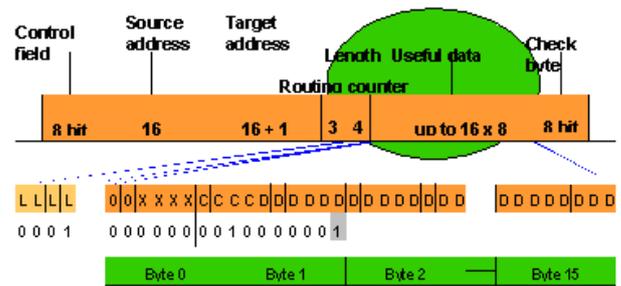
Figure 3: The Data Telegram.

The reply may be a 1-bit message as in the example of the "write" command, or it can use up to 13 bytes (bytes 2 to 15).

The length of the data is dependent on the EIS type in use.

Cable Lengths
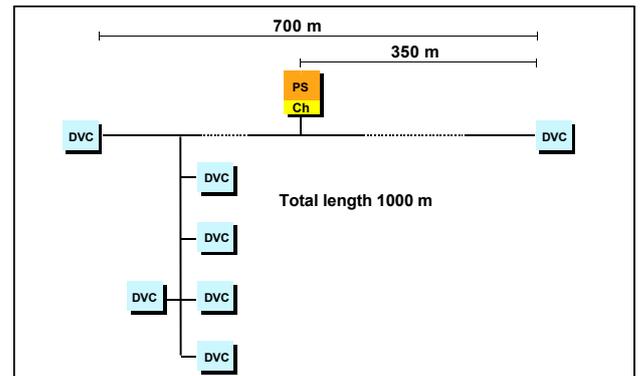
Figure 4: Permitted cable lengths.

Within a bus line, the following cable lengths are permitted:

Power Supply Unit - Bus device (350 m)

Bus device - Bus device (700 m)

Total bus line length (1000 m)

Minimum distance between 2 power supply units on one line (200 m)

3.3   Topology
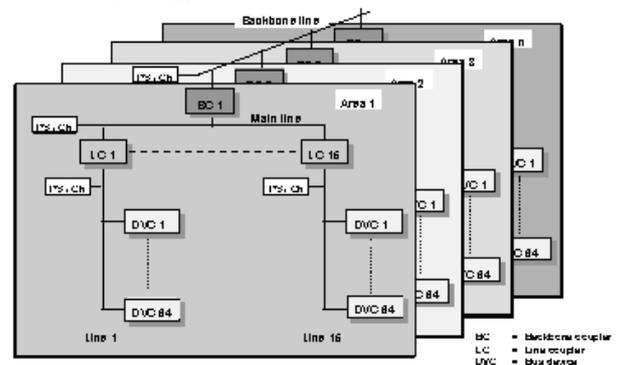
Figure 5: Topology.

3.3.1   Topology Line

Each bus device (DVC) can exchange information with any other device by means of telegrams. One line consists of a maximum of 4 line segments, each with a maximum of 64 bus devices. Each segment requires an appropriate power supply. The actual number of devices is dependent on the power supply selected and the power input of the individual devices.

3.3.2 Topology Area

If more than 1 line is to be used or if a different structure is to be selected, then up to 15 lines can be connected to a main line via a line coupler (LC). This is called an area. It is also possible to have up to 64 bus devices on the main line. The maximum number of bus devices on the main line decreases by the number of line couplers in use. Each line, including the main line, must have its own power supply unit. Line repeaters may not be used on backbone or main lines.

3.3.3 Topology: Several Areas

The installation bus can be expanded by means of a backbone line. The backbone coupler (BC) connects its area to the backbone line. It is also possible to have bus devices on the backbone line. The maximum number of bus devices on the backbone line decreases by the number of backbone couplers in use. Within a maximum of 15 functional areas, more than 64,000 bus devices can be connected to the bus system. By dividing the EIB installation into lines and areas, the functional reliability is increased considerably.

3.4 Telegram

When an event occurs (e.g. when a pushbutton is pressed), the bus device sends a telegram to the bus. The transmission starts after the bus has remained unoccupied for at least the time period t1. Once the transmission of the telegram is complete, the bus devices use the time t2 to check whether the telegram has been received correctly. All "addressed" bus devices acknowledge the receipt of the telegram simultaneously.
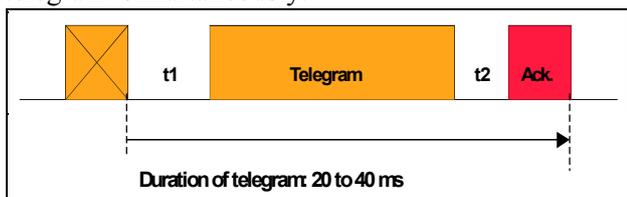
Figure 6: Duration of telegram.

3.4.1. Telegram Structure

The telegram consists of bus-specific data and useful data which provide information about the event (e.g. pressing a push button in EIB). The information is transmitted in its entirety in the form of 8-bit long characters. Test data for the detection of transmission errors is also transferred in the telegram: this guarantees an extremely high level of transmission reliability.
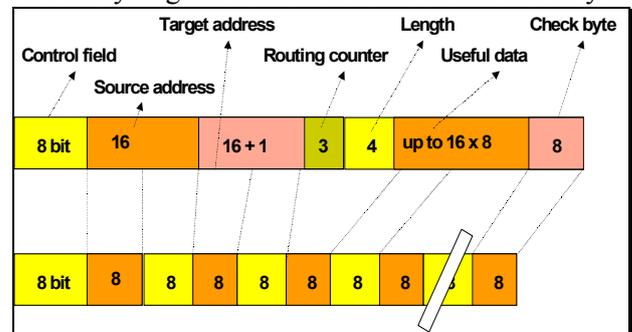
Figure 7: Telegram structure.

The telegram is transmitted at a bit speed of 9600 bit/sec, i.e. one bit occupies the bus for 1/9600 sec or 104 μs. A switching telegram (including acknowledgement) occupies the bus for 20 ms. Telegrams for text transmission occupy the bus for up to 40 ms.

3.5 EIB BUS DEVICES
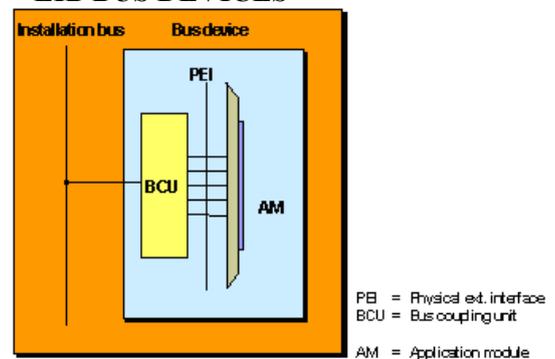
Figure 8: EUB bus devices.

3.5.1 Introduction to EIB BUS DEVICES

A functioning bus device (e.g. dimming actuator/drive control, multi-functional push button, fire sensor, …) principally consists of three parts:

bus coupling unit (BCU)
application module (AM)
application program (AP)

Bus coupling units and application modules are offered on the market either separated or integrated into one housing. They must however be from the same manufacturer.

If separated, the application module is connected to the BCU via a standardised application interface, the Physical External

Interface or PEI. This 10 or 12 pin PEI serves as an interface to exchange messages between both parts (5 pins)

the power supply of the application module (2 pins)

When the BCU is an integrated part of the bus device, it has mostly been built into the bus device via a BIM (Bus Interface Module) or via an EIB chip set by the manufacturer of the bus device. Principally a BIM is derived from a bus coupling unit by omitting the latter's housing and a number of other components. An EIB chip set consists of the core of a BIM, i.e. the controller and the transceiver.

The BCU is currently available for connection to two different media: Twisted Pair (Safe Extra Low Voltage 32V) or Power - line (mains power). Connection to radio frequency networks and the infrared medium is currently under development.

Each bus device has its own intelligence owing to the integrated BCU: this is the reason why EIB is run as a decentralised system and does not need a central supervising unit (e.g. a computer). The central functions (e.g. supervision) can, however, if needed, be assumed by visualisation and control software installed on PCs.

Bus devices can principally be divided into two classes: sensors and actuators. In the case of a sensor, the application module transfers information to the BCU. The latter codes this data and sends it on the bus. The BCU therefore checks the state of the application module at appropriate intervals. In the case of an actuator, the BCU receives telegrams from the bus, decodes them and passes on this information to the application module. An EIB bus device receives its specific function once the appropriate application program for the application module has been loaded into the (universal) BCU (in most cases this is done via the EIB Tool Software).
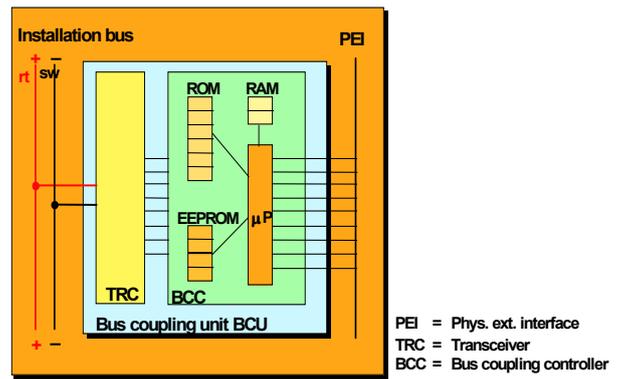
Figure 9: EIB interfaces.

3.5.2 Bus Coupling Unit

The BCU principally consists of two parts: controller and transceiver. The controller in turn consists of a microprocessor (μP) offering the following memory types: ROM, RAM and EEPROM.
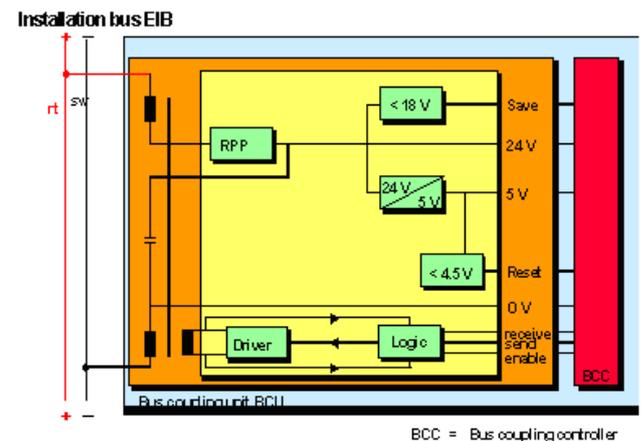
Figure 10: Bus Coupling Unit.

The TP transceiver has the following functions:

Separation or superimposing of the direct current and data,

Reverse voltage protection (RPP),

Generation of stabilised voltages of 5 respectively 24V,

Initiating a data back-up (U - save) if the bus voltage drops below 18V,

Triggering a processor reset if the voltage drops below 4.5 V,

Driver for transmitting and receiving,

Sending and receiving logic.

3.5.3 Type Definition of an Application Module
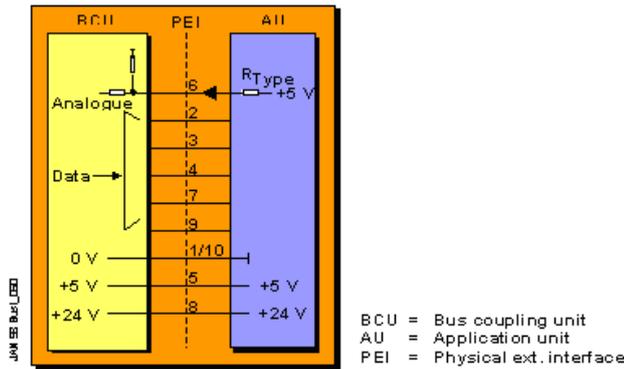
Figure 11:   Interface between BCU and Application Unit.

Via a resistor (R-Type) in the application module, the bus coupling unit is able to detect via pin 6 of the PEI, whether a suitable application module has been mounted on the BCU.
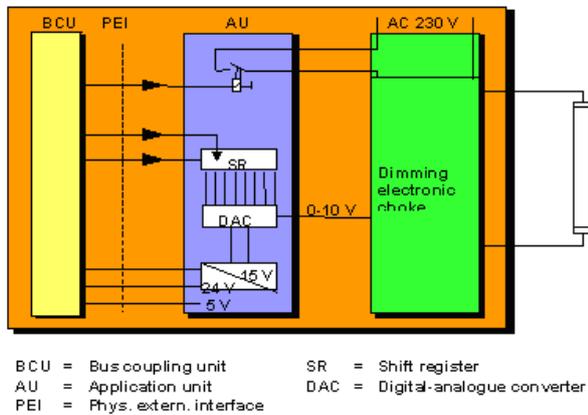
Figure 12: Detection of the Application Unit via the PEI.

3.5.4 Application Function: 'Dimming Actuator'

During the dimming period, the bus coupling unit increases or decreases the digital brightness value according to the set regulating time. The brightness value is continuously passed on to the shift register (SR) in the application unit. The 8 bit long data word allows the generation of 2^8 = 256 brightness values. The data word is fed into the digital/analogue converter (DAC), which then generates the appropriate control voltage in the range of 0 to 10V. The dimmer's electronic choke uses the voltage to control the light emission of a fluorescent tube. The power circuit breaker in the application unit is used to (dis)connect the mains voltage.

3.6   EIB POWERLINE

3.6.1 Introduction to EIB Power line

EIB Power line allows the transmission of telegrams across the 230/400 V network. A separate bus line is therefore not necessary. Telegram repetition takes place via external and neutral conductors which must be connected to every device. The system is compatible with EIB components and the corresponding tools. It is possible for instance to plug a flush-mounted application module onto a flush-mounted mains coupler and to load the application software via the 'bus cable' (230/400 V supply line) into the mains coupler. In spite of the undefined transmission characteristics of the energy supply system (caused by cable types, cable length, type and number of connected devices,…), EIB Power line ensures a high level of security during telegram transmission. The system works bi-directionally in a half-duplex operation i.e. every device can transmit and receive.

3.6.2   Standardisation

In Europe, signal transmission via the energy supply system is regulated by the CENELEC standard EN 50065. Part 1 of this standard defines general requirements, frequency ranges, transmission levels and requirements for electromagnetic compatibility (EMC). EIB Power line uses the frequencies 105.6 kHz and 115.2 kHz for transmission.

Due to the middle frequency of 110 kHz, the EIB Power line system is sometimes referred to as PL110. As the standard only allows a maximum transmission level of 116 dB μV, the devices are sometimes called 'class 116' devices.

3.6.3 Transmission Process

Owing to the continuous progress made in the miniaturisation of electronics, it was possible to apply a new transmission process for EIB Power line i.e. Spread Frequency Shift Keying or SFSK for short. It functions as follows:

If a '0' is transmitted, the transmitter produces a frequency of 105.6 kHz and the supply voltage is superimposed.

If a '1' is transmitted, a frequency of 115.2 kHz is used.

In order to ensure a safe transmission at the highest possible speed, the rate of 1200 bit/s is set in all mains couplers which corresponds to a bit duration of 833 μs.

All mains couplers are permanently in receive mode. A received signal (also noise) is permanently converted into a digital value.

This digital value is now fed into two correlators (probability comparators) which compare the received digital value with a

stored, digital frequency reference pattern.

There are two correlators in each mains coupler: one for the '0' bit and one for the '1' bit.

The correlators can differentiate with a calculable probability that:

- It is a '0'
- It is a '1'
- it is undefined (noise) and the bit is therefore rejected.
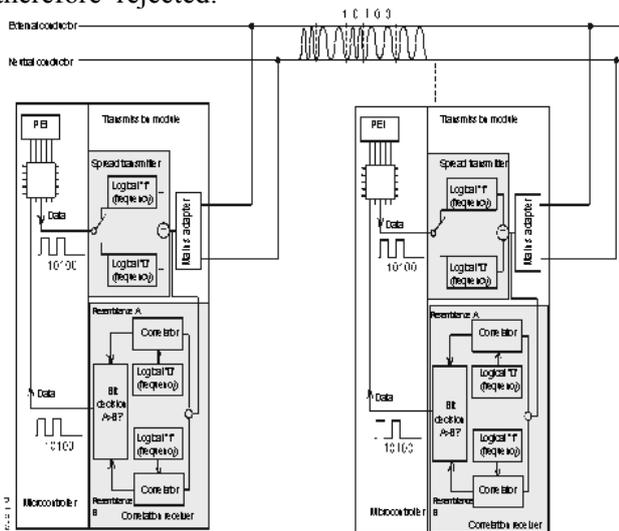
Figure 13: The transmission process.

The combination of bit patterns as well as specialised error detection methods allow a guaranteed level of telegram recognition. In addition, a further innovative technique is used, namely the permanent and automatic adaptation of transmission power and receiving sensitivity. This process allows continuous adaptation of the transmission power to the network characteristics, thereby taking into account that the maximum transmission level is never exceeded. All receivers likewise permanently control their sensitivity according to the network characteristics. This results in an optimum transmission range even under constantly changing supply conditions.
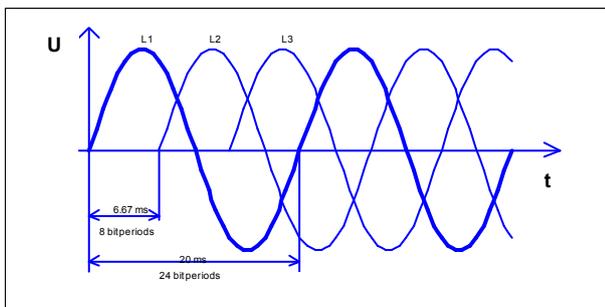
Figure 14: Phase coupling.

3.6.4 Phase Coupling

In order to ensure that data is transmitted on all three conductors, the following two possibilities exist:

• In smaller installations, a passive phase coupling across the connections to devices with more than one phase (e.g. gas heater, electric cooker) can suffice. However, in order to ensure a defined coupling between the three phases, the use of a phase coupler is recommended.

• In larger installations, the integration of a repeater is recommended. The repeater has 4 poles (3 external conductors and 1 neutral conductor) and couples signals with the highest possible transmission level on each external conductor.

Phase couplers and repeaters may not be installed simultaneously in an installation. This means that if a repeater is retrofitted in an installation with an integrated phase coupler, the phase coupler must be removed.

3.6.5 Telegram Transmission

Compared to the EIB-TP telegram, EIB Power line requires additional information during the transmission of data.
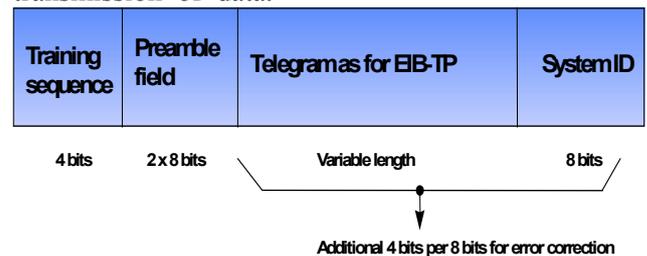
Figure 15: Additional information included in the telegram due to EIB Power Line.

3.6.6 Training Sequence

The training sequence acts as the automatic reception adjustment of the receivers (thus of all mains couplers except those that are transmitting). The receivers adjust their reception to the network conditions.

3.6.7 Preamble field

The preamble field has two functions:

It marks the start of the transmission.

It controls the bus access.

3.6.8 Telegram

After this, the actual telegram is transmitted (as on EIB-TP), in which four additional bits of test data are added to every transmitted byte. With the help of this test data, one bit errors can be corrected and multi-bit errors can be detected.

3.6.9 System ID

Each telegram is terminated by a field which contains the System ID. The System ID

consists of 8 bits (with an additional 4 bits of test data) and can be set by the project engineer of the installation between 1 and 254. The System ID is reserved for information to all devices.

The objective of the System ID is to prevent EIB Power line installations that are positioned in close proximity from influencing each other. For this purpose, a distinct System ID is attributed to each EIB Power line installation. As the System ID is transmitted in the telegram, each receiver can establish whether the telegram belongs to its installation and then react accordingly.

Training sequence	Preamble field	Reply telegram
4 bits	2 x 8 bits	8 bits + 4 bits for error correction

Figure 16: Reply Telegram.

3.6.10 Reply Telegram

The reply telegram is produced as a result of the received telegram and must reach the transmitter after a certain period of time. Compared to EIB-TP, only two reply telegrams are transmitted:

- ACK:

Transmission was successful.

- NACK:

Transmission was not successful. This reply telegram is only used by the repeater.

If the reply telegram is not sent, the telegram is repeated. The further process is dependent on whether the system contains a repeater or not.

3.6.11 Bus Access Procedure

The collision problem has been resolved by the use of special time slots i.e. every mains coupler may only transmit during specified periods. However, if several mains couplers try to start transmission simultaneously, the following applies:

- The mains couplers detect a collision and determine a random priority for the transmission of telegrams.
- The mains couplers do not detect a collision and the telegrams are lost.

3.6.12 Topology / Addressing
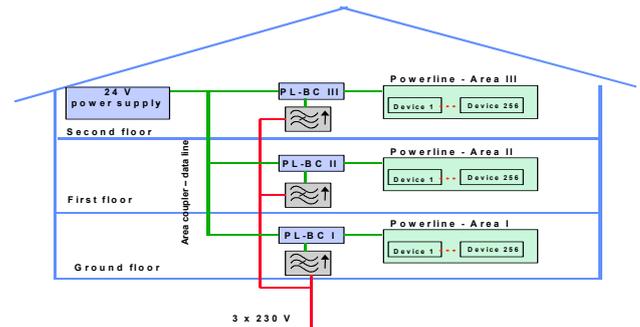
Figure 17: Topology addressing.

The logical addressing of EIB-PL is compatible with EIB-TP. A maximum of 8 areas (compared to 15 for EIB-TP) can be addressed, each with 16 lines of 256 devices. Areas containing PL signals must be separated from the general supply system via band-stop filters. The media coupler forms the interface to EIB-TP in combined installations. In a detached house it is not strictly necessary to split up the devices into lines and areas via corresponding couplers, provided that the number of PL devices does not exceed 256. All PL devices can exchange data across all 3 phases via the 230 V installation network, as soon as a phase coupler or repeater has been installed.

In larger installations, the bus load is reduced via a logical and physical classification of the EIB-PL installation into a maximum of 8 areas (with up to 255 PL devices per area). The physical separation of the individual areas is achieved using band-stop filters. Data can be transmitted from one area to another via a separate data cable between the various backbone couplers. The active phase coupling on the PL side is carried out by the backbone coupler. The physical separation and the filter table of the backbone coupler allow a selective transmission of telegrams into the neighbouring area. The bus load in the entire system is thus considerably reduced.

3 Upgrading of Facades and Energy Performance of Buildings in Greece

In another paper, which was presented at the AIVC 2008 conference [7], was demonstrated, that the forms taken by both the opaque and transparent elements of facades play a particularly important role in the upgrading and rehabilitation of office buildings. In these cases there are significant opportunities for applying structural interventions in the building facades without

interrupting the operation of the building, whilst improving the overall energy performance for a wide variety of climatic conditions.

This paper examines aspects of the upgrading and rehabilitation of office building facades in urban environments, within the framework of the overall energy behavior of buildings in mild Mediterranean climates. For this reason a specimen of office buildings in Greece is examined. Fenestration types, external and internal shading devices, opaque façade elements and external finishing are examined, through implementing energy simulations and –in certain cases- conducting measurements and analyzing information gathered from questionnaires distributed to employees.

Special emphasis was placed on the effect of the urban environment on solar gains and natural ventilation. Impacts on the mechanical and hybrid ventilation systems were also taken into account.

Some of the outcomes are as follows: The specific heating and cooling consumptions in the examined buildings were between 95 and 120 kWh/m^2 per year for heating and between 30 and 48 kWh/m^2 per year for cooling demands. The most significant factors affecting energy consumptions were the F/V ratio, the extent of glazing in the facades and the incident solar radiation. Dense urban environment, orientation, A/V ratio and night ventilation reduced the cooling demand by more than 73% of the original condition, compared to 137% if there was only renovation of equipment and no retrofitting. The benefits of this strategy on thermal comfort were immediately apparent to the end-users. The cooling demand could be reduced by a further 61% if external shading devices were fitted.

It is therefore clear that the upgrading of facades should be carefully simulated during the early design stages, even in common non-low energy office buildings. The outcomes could lead to significant changes in the HVAC design. Effective upgrading of building facades could lead to an improvement in responses to employee questionnaires, even if no other measures were implemented.

4   The Influence of the Form Structure on the Energy Behavior of Office and Administration Buildings

Next, it will be examined the form structure as a bioclimatic factor: i.e. its influence on the energy behavior of a building [8], [9], [10], [11] and [12].

The examples mentioned are restrained to office and administration buildings. While being in the process of planning, an architect should take into account three major parameters. The project has to be aesthetic, functional and friendly to the environment. The following discussion is about the interactions between these factors and their influence on the balance that a building should have.

In the following cases, we will examine the impact of a building's form structure on its energy behavior, as determined by the EnEV calculating tool.

In order to obtain comparable results, we have to use a common, objective basis, which, in our case, is the A/V ratio. Thus, all buildings could be compared according to their total surface A and their volume V. As we are going to see further, the results can sometimes be confusing. Therefore, it is of high importance to show the exact function of the A/V ratio and try to define the point, up to where it can give an architect or planner useful information for his/her work.

4.1. Introduction
Definition:
The A/V ratio is the ratio of the surface of a building's shell to its volume [1/m]. Therefore, the A/V proportion is a rate of great importance for the architectural design, as it can influence and help reducing the heat transmission losses of a building. The smaller the shell surface A is, in proportion to the buildings volume V, the less the energy losses due to heat transmission.

Unheated rooms, like staircases, basements, cellars etc., do not belong to the heated used surfaces. A clear thermal demarcation between heated and unheated spaces is of high importance, although, in many cases, not always significant from an architectural point of view, for fissured heated volumes may occur. Therefore, the clear geometrical structure of the building is strongly depending on the heated space volume/volume space.

4.2. Case Studies
4.2.1.1 1st Case: Structure Form

In this first case, we compare four office buildings having the same volume V. We examine four buildings of different form types and, consequently, of different total surfaces A: a compact one, an elongated, an L–shaped and one with an internal courtyard.
Using the EnEV calculator, it is shown how the

Annual Primary Energy Requirements (APER) change according to the fluctuation of the A/V ratio. Office buildings should be architecturally attractive and communicate a sense of transparency and openness. In the following examples though, in order to ensure comparability, we assume that buildings have no openings.

We define the first building's A/V ratio as the reference value for all other buildings examined. In tables 1 to 4, we observe that the Annual Primary Energy Requirements rise together with the A/V ratio. The second and third example indicate that while the A/V ratio remains constant, the Annual Primary Energy Requirements rate increases. We can conclude that the more surfaces a building has, the more energy losses it suffers.

Table 1: 1st Case: 1st Example

General		Annual Primary Energy Requireme
Volume	440 m³	absolute 18213,86 kWh/a
A/V	0,81	is 129,36 kWh/(m²a)
relative	100%	Specific Surface-Related Transmitt Losses
Windows/ Surface	0%	allowed 0,48 w/(m²k)
		is 0,36 w/(m²k)
		relative 25,3 %

Table 2: 1st Case: 2nd Example

General		Annual Primary Energy Requirements
Volume	440 m³	absolute 19246,46 kWh/a
A/V	0,89	is 136,69 kWh/(m²a)
relative	110%	Specific Surface-Related Transmittive Heat Losses
Windows/ Surface	0%	allowed 0,47 w/(m²k)
		is 0,37 w/(m²k)
		relative 22,1 %

Table 3: 1st Case: 3rd Example

General		Annual Primary Energy Requirements
Volume	440 m³	absolute 19250,74 kWh/a
A/V	0,89	is 136,72 kWh/(m²a)
relative	110%	Specific Surface-Related Transmittive Heat Losses
Windows/ Surface	0%	allowed 0,47 w/(m²k)
		is 0,37 w/(m²k)
		relative 22,1 %

Table 3: 1st Case: 3rd Example

General		Annual Primary Energy Requir
Volume	440 m³	absolute 19250,74 kWh/
A/V	0,89	is 136,72 kWh/(m
relative	110%	Specific Surface-Related Trans Heat Losses
Windows/ Surface	0%	allowed 0,47 w/(m²k)
		is 0,37 w/(m²k)

| | | relative   22,1 % |

Table 4: 1st Case: 4th Example

General		Annual Primary Energy Requirements
Volume	440 m³	absolute 22495,96 kWh/a
A/V	1,23	is 159,77 kWh/(m²a)
relative	152%	Specific Surface-Related Transmittive Heat Losses
Windows/ Surface	0%	allowed 0,44 w/(m²k)
		is 0,34 w/(m²k)
		relative 22,7 %

4.2.1.2 Conclusion

In this case, the surface of the buildings shell A increases, while the volume V remains constant. It is clear that both the A/V ratio and the Annual Primary Energy Requirements increase as well. Projections, set-backs, offsets, increase the surface of the building and, thus, the A/V ratio.

4.2.2.1 2nd Case: Built-up density

In this case, we examine the impact of the density of a building on the APER. In the first example, we observe the energy behaviour of 8 identical but detached volumes, having a sum of 48 surfaces. In the second example, the same volumes are combined, so that they have a sum of 36 surfaces. In the third examined, the resulting surfaces are 28 and in the last one 24. We can see in the tables 5-8 the tremendous difference of the Annual Primary Energy Requirements.

Table 5: 2nd Case: 1st Example

General		Annual Primary Energy Requirements
Volume	1000 m³	absolute 59875,76 kWh/a
A/V	1,2	is 1496,88 kWh/(m²a)
relative	148,1%	Specific Surface-Related Transmittive Heat Losses
Windows/ Surface	0%	allowed 3,52 w/(m²k)
		is 2,96 w/(m²k)
		relative 128 %

Table 6: 2nd Case: 2nd Example

General		Annual Primary Energy Requirements

Volume	1000 m³	absolute	43206,36 kWh/a
A/V	0,9	is	270,04 kWh/(m²a)
relative	111 %	Specific Surface-Related Transmittive Heat Losses	
Windows/ Surface	0%	allowed	0,94 w/(m²k)
		is	0,72 w/(m²k)
		relative	44,8 %

Table 7: 2nd Case: 3rd Example

General		Annual Primary Energy Requirements	
Volume	1000 m³	absolute	36128,22 kWh/a
A/V	0,7	is	112,90 kWh/(m²a)
relative	86,4%	Specific Surface-Related Transmittive Heat Losses	
Windows/ Surface	0%	allowed	0,51 w/(m²k)
		is	0,38 w/(m²k)
		relative	26,9 %

Table 8: 2nd Case: 4th Example

General		Annual Primary Energy Requirements	
Volume	1000 m³	absolute	32786,53 kWh/a
A/V	0,6	is	102,46 kWh/(m²a)
relative	74%	Specific Surface-Related Transmittive Heat Losses	
Windows/ Surface	0%	allowed	0,55 w/(m²k)
		is	0,37 w/(m²k)
		relative	33,1 %

obvious!

Diagram 1: 3rd Case: 1st Example, Annual Primary Energy Demand
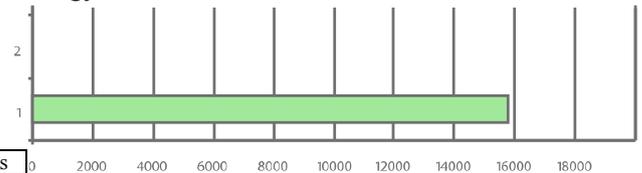
Diagram 2: 3rd Case: 2nd Example, Annual Primary Energy Demand
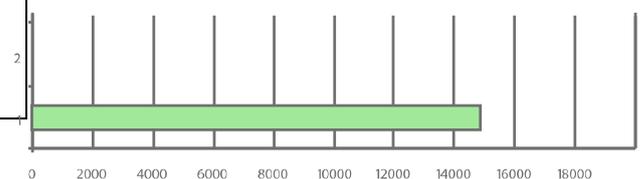
Diagram 3: 3rd Case: 3rd Example, Annual Primary Energy Demand
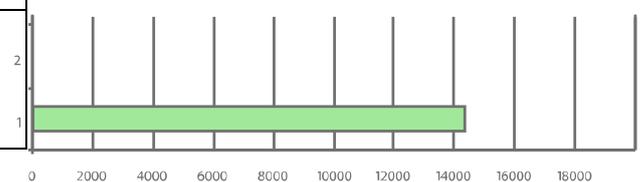
Diagram 4: 3rd Case: 4th Example, Annual Primary Energy Demand

4.2.2.2 Conclusion

Compact buildings with small A/V ratio (like office buildings, ex. 3&4) have less heat losses than others, semi-detached (ex. 2) or detached buildings (like a row of self contained houses, ex. 1). This happens because the total surface exposed to the air atmosphere is smaller. Therefore, by small buildings, the essential subject is the reduce of the APER. In big public buildings though, ventilation, air-conditioning and daylight play a major role in their energy balance. These loads are not directly related to the A/V ratio, but are subject to other design and operational parameters.

4.2.3.1 3rd Case: Thermal Insulation

In the following case four walls of same thickness are being examined. Each time the thickness of their thermal insulation is doubled. As shown in the following diagrams, the effect of this action is

4.2.3.2 Conclusion

The thicker the thermal insulation, the less is the Annual Primary Energy Requirements of a building. This is due to the minimization of the transmittance of energy losses.

4.2.4.1 4th Case: Volume Rate

At this point, we examine the effect of a volume increase on the Annual Primary Energy Requirements of a building. In diagrams 5 to 7, we observe the vast difference in the APER by doubling the edges of the examined building.
This means that the volume increases in both cases by 700%. Looking closely at the diagrams, we observe that the APER increase as well, but not proportionally. As a matter of fact, the absolute rate of APER per sq. meter decreases.

This can be explained by the conclusions already made in the second case.
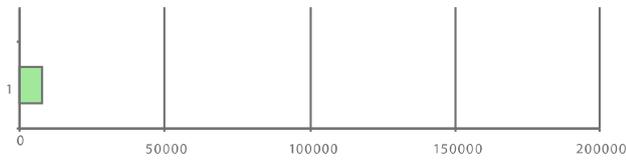
Diagram 5: 4th Case: 1st Example, Annual Primary Energy Demand
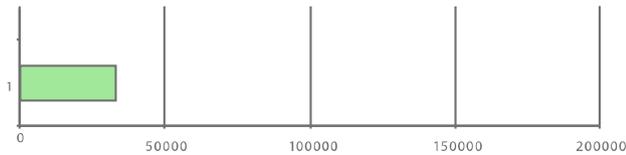
Diagram 6: 4th Case: 2nd Example, Annual Primary Energy Demand
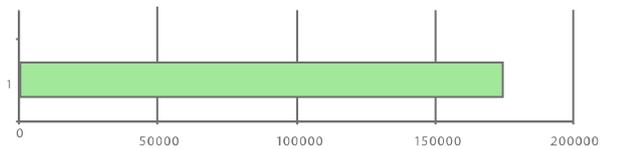
Diagram 7: 4th Case: 3rd Example, Annual Primary Energy Demand

4.2.4.2 Conclusion

The heating loss due to transmission plays the deciding role for buildings with small volume (A/V small), such as self-contained houses. The larger the facade to the building volume is, the bigger is the surface that should be isolated. On the contrary, the major issue in buildings with large volume (A/V high) (industrial, administration) is ventilation and cooling, especially for Mediterranean countries, such as Greece.

4.2.5.1 5th Case: Position

Although the A/V ratio has proved to be an excellent tool, it does not take into consideration all parameters affecting the energy behaviour of a building, like shown in the following examples. In the first one the volume stands in vertical position, in the second horizontal to the ground with its smaller surface and in the last the volume is in horizontal position with its big surface.
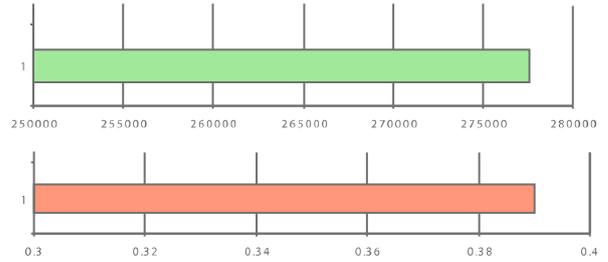
Diagram 8: 5th Case: 1st Example, Annual Primary Energy Demand and U-Rate
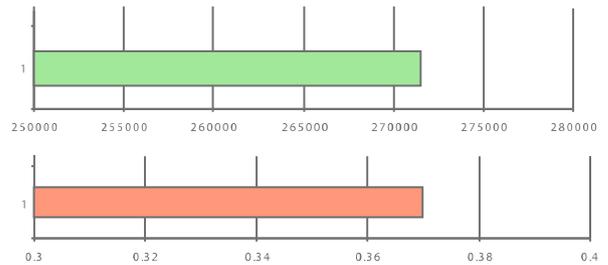
Diagram 9: 5th Case: 2nd Example, Annual Primary Energy Demand and U-Rate
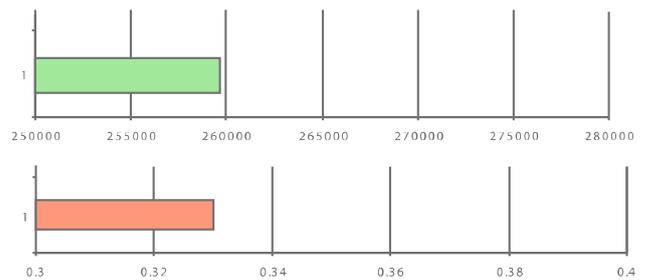
Diagram 10: 5th Case: 3rd Example, Annual Primary Energy Demand and U-Rate

4.2.5.2 Conclusion

One should consider though that the A/V ratio does not take into account the following fact: The heat loss of a building diverges according to the percentage of total surface adjacent to the ground. More specific, a surface exposed to the air atmosphere has much more heat losses then one adjacent to the ground. Assuming constant U-rate, the specific heat capacity of the building in the up straight position is 10% higher.

The A/V ratio though cannot separate a high-rise building from another with the exact same volume structure but lying on the ground. Thus, two structurally identical buildings have the same A/V ratio regardless whether in horizontal or vertical position.

5 The Cube as a Building
5.1 The Difficulty of the Cube Form

All these cases show us, that the ideal form

structure of a building, with respect to its energy behavior, is the Cube. It combines an excellent A/V ratio with a compact form, two basic architectural weapons against energy losses. Nevertheless, this form is very difficult to handle and to create an interior interesting spatial sculpture. A building in the shape of a cube is not always practical. There are though many remarkable buildings all over the world. Here is a small look back on the unforgettable Expo 2000 in Hanover, Germany, the Museum of Arts in Stuttgart, the chain of the famous cube Hotels and the Ritter-Museum.

In this great variety of alternatives to solve this architectural riddle, a planner should always set his/her first priority in conceiving and constructing a building with the best energy data according to its use, its position and the legal conditions.

5.2 Museum of Arts, Stuttgart

This glass cube, with a total of 3.400 m2 glass surface and its clear corners is composed of heat insulated milk-glassed elements. The small intermediate space between the glasses is filled with Argon-gas in order to improve the U-rate of the pane of glass.

Special co-ordinated coatings allow only 24% of the heat energy to enter into the building by maximal light-transmission.

The building is equipped with 4 exhaust air systems and 2 supply air systems.

Picture 1: Museum of Arts, Stuttgart

5.3 The Ritter-Museum

The Ritter – Museum was created by the Swiss Architect Max Dudler and lies next to the Chocolate Industry Ritter Sport. With flat facades from limestone and large openings, the building gives a monoliths impression. The floor area of the building is 44x44 m2 and gains its energy

demands from renewable sources.

The energy used for heating and climate control is supplied almost entirely by regenerative sources, such as solar, biomass and geothermal energy. The energy required for heating-circuit water and cooling water is provided by a solar energy collector, a wood pellet combustion system, and a heat pump. The solar energy system consists of 47 CPC evacuated tube collectors. With a total output of 100 kW, this covers 40% of the overall heat requirements.

In addition, the Museum has a heat pump linked with the building's 73 foundation piers, all connected by a circulating water supply. 40% of the heat comes from the ground. Heat release is chiefly performed by a floor heating system, which can likewise cool the Museum's galleries when required.

The geothermal probes, the evacuated tube collectors, the absorption refrigerator, the wood pellet boilers and the heat exchanger are all linked together by means of hydraulic switches. This allows, the absorption refrigerator to be used as a cooling device in summer and as a heat pump in winter, and the geothermal probes as coolers in summer and as a means of sourcing heat in winter.

Picture 2: The Ritter Museum

6 A more precise approach for thermal, ventilation and air contaminant problems in buildings
6.1 Introduction

The A / V criterion is a bulk criterion. More precise results may be obtained via simulations. In a third paper [13] simulations were done taking into account the work presented in [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], and [27].

The simulations were performed implementing the

combined use of thermal simulation software Suncode and the ventilation and air contaminant code of COMIS.

6.2 Introduction Basic principles and equations of the implemented air flow and thermal nodal modelling

6.2.1. Air flow modeling

Air flow through the rooms of a building originates from pressure distribution around and within the building itself. Pressure distribution is due to the combined actions of wind, thermal buoyancy (stack effect) and mechanical ventilation - if it exists. Due to the turbulence characteristic of the wind flow in the lower layers of the atmosphere, the pressure field driven by the wind on building surfaces is always unsteady and difficult to predict and simulate. Differential pressure due to the stack effect depends on density field and on the mechanical ventilation (Grosso 1994), (Feustel 1996).

Wind flows produce a velocity and pressure field around buildings. The relationship, for free stream flow, between velocity and related pressure at different locations of the flow field can be obtained from Bernoulli's equation. Assuming constant density along a streamline at a given height Bernoulli's equation can be simplified thus:

$$P_{stat} + \frac{1}{2} \rho \overline{v}^2 = \text{constant} \qquad (1)$$

The wind velocity profile is calculated by a power law expression.

$$\frac{v(z)}{v(z_{ref})} = \left\{ \frac{z}{z_{ref}} \right\}^{\alpha} \qquad (2)$$

The value of the exponent a increases with the increasing roughness of the solid boundary. The wind pressure distribution on the building envelope is described by dimensionless pressure coefficients - the ratio of the surface dynamic pressure to the dynamic pressure in the undisturbed flow pattern measured at a reference height. The pressure coefficient Cp at point k(x,y,z), with reference dynamic pressure P_{dyn} related at height z_{ref}, for a given wind direction φ can be described by:

$$Cp_k(z_{ref}, j) = \frac{P_k - P_0(z)}{P_{dyn}(z_{ref})} \qquad (3)$$

where:

$$P_{dyn}(z_{ref}) = \frac{1}{2} \rho_0 v^2(z_{ref}) \qquad (4)$$

The pressure coefficients of the under examination building are calculated by implementing a parametrical calculation algorithm taking into account climatic, building and environmental parameters (Allen 1984), (Grosso 1994). The results were compared with wind test studies in the bibliography for similar buildings (Kendrick 1993), (Palmiter et al 1991), (Bluyssen et al 1996), (Grosso 1994), (Wittchen et al 2002).

The effect of thermal buoyancy or the stack effect is the other natural phenomenon driving differential pressure in a building. It is due to density differences between inside and outside air or between two zones of a building. The density is mainly a function of temperature and the moisture content of air. The local pressure difference between two points Z_i and Z_j, in the two zones, if M and N are two zones on the opposite sides of a leakage is given by:

$$P_i - P_j = P_m - P_n \, P_s \qquad (5)$$

where P_s takes the stack effect into account:

$$P_s = \rho_m \, g \, (Z_m - Z_i) - \rho_n \, g \, (Z_n - Z_j) \qquad (6)$$

Z_m, P_m, T_m, ρ_m, Z_n, P_n, T_n, ρ_m are respectively the height, pressure, air pressure and air density at the reference points.

Natural ventilation phenomena in buildings could be categorized mainly as flow through cracks and flow through large openings. The influence of HVAC systems should also be calculated.

Simulation of the air leakage characteristics of cracks under real conditions, based on the exponential power law, takes the general form of:

$$Q = C_s \, v^{1-2n} \, \rho^{-n} \, (\Delta P)^n \qquad (7)$$

Air mass flow Q, is described here as a function of pressure difference ΔP. The coefficient C depends on the crack form (duct shape). The flow regime (laminar, transitive or turbulent), the type and geometry of the crack and the temperature of the air in the cracks are also taken into account (Feustel 1996), (van der Maas 1992), (Vandele et al 1989).

The flow through large openings is simulated to fit easily into the network definition and to model the phenomena that influence the behavior of large openings. The main assumptions in the COMIS model are: a) steady flow, in viscid and incompressible fluid; b) linear density stratification on both sides of the opening; c) turbulence effects represented by an equivalent pressure difference profile, and d) effects of reduction of the effective area of the aperture represented by a single coefficient. A general

description of the problem to be solved is given in Fig. 18.
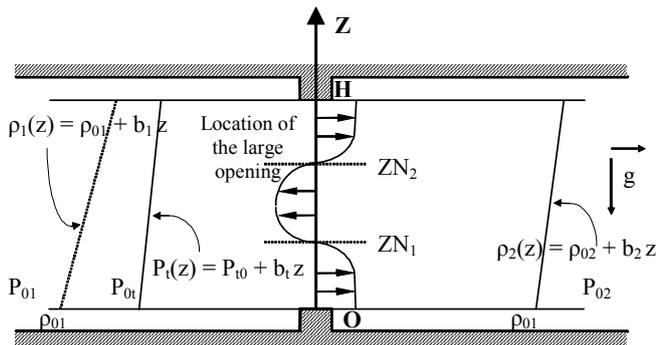
Figure 18: General problem of gravitational flow through a large vertical opening (based on Vandele et al 1989).

On each side of the opening, linear density stratification is assumed:

$$\rho_i(z) = \rho_{0\,i} + b_i\ z \qquad (8)$$

and a linear pressure difference simulating the effect of turbulence is introduced:

$$\Delta P_t = P_{t0} + b_t\ z \qquad (9)$$

The airflows moving in both ways through the opening are expressed as follows, after integrations in the intervals defined by the physical limits (see Fig 1) of the opening and the position of the neutral planes:

$$\overset{\bullet}{m}_{0,z1} = Cd\ \theta \int_{z=0}^{z=z1} \rho\ v(z)\ W\ dz \qquad (10)$$

$$\overset{\bullet}{m}_{z1,z2} = Cd\ \theta \int_{z=z1}^{z=z2} \rho\ v(z)\ W\ dz \qquad (11)$$

$$\overset{\bullet}{m}_{z2,H} = Cd\ \theta \int_{z=z2}^{z=H} \rho\ v(z)\ W\ dz \qquad (12)$$

From the preceding equation it appears that the flow through a large opening is directly proportional to an empirical discharge coefficient Cd, taking into account the contraction of the flow due to the existence of the opening. Theoretically it depends on the fluid and the local flow characteristics caused by the shape of the opening. Its value varies from 0.61 for sharp-edged orifices to 0.98 for trumpet-shaped nozzles. Generally, these integrals have no analytical solutions and they have to be computed by numerical means (e.g. a classic Simpson integration). This numerical solution is general but it is also time-consuming and is reserved for more general case. Further analysis of the problem may be found in the bibliography (Kendrick 1993), (Feustel 1996). Nodal natural ventilation programs like the COMIS model which is implemented in this work establish the infiltration and ventilation rates in a

building by solving of a non-linear system of equations that represents a network. An iterative method can be used in which a linear system of equations is solved at each step of the process. The network consists of pressure nodes and links. A mass flow balance must exist at each node, as described by the following flow balance equation:

$$f(P) = \sum_i \frac{dm_i}{dt} = 0 \qquad (13)$$

and in vector form for all nodes:

$$\mathbf{f(P)} = 0 \qquad (14)$$

An appropriate function describes the flow rate as a function of pressure difference for each link. Non-linear expressions of the following type are predominant; for a better understanding we here disregard the temperature correction factor K. introduced in

$$\overset{\bullet}{m} = C_{,m}(\Delta P)^n, \qquad \text{where} \quad 0.5 \le n \le 1.0 \quad (15)$$

Equation (15) is obviously a non-linear system of equations.

The Newton-Raphson method finds the next approximation in the multi-dimensional case through the following iteration function h(P):

$$\mathbf{P_{n+1}} = \mathbf{P_n} - \frac{\mathbf{f(P_n)}}{\mathbf{J(P_n)}} \qquad (16)$$

where $\mathbf{J(P_n)}$ is the Jacobian matrix. The Jacobian matrix is obviously similar to $f'(P_n)$. The matrix consists of the partial derivatives of all the flow balance equations f regarding all pressures P

6.2.2. Thermal modeling

A nodal thermal model like the Suncode which is implemented here has similar structure to the nodal multizone air infiltration model. It is based on the concept of the thermal zone, which might be a room or a total of rooms or a whole building under a single zone temperature node. This is a conductance weighted average of all temperatures which affect the zone. Each zone has independent solar inputs, independent HVAC systems and natural ventilation conditions (Palmiter et al 1991), (van der Maas 1990), (Vandele 1989). Zones may be connected by walls which are connected by a constant heat transfer coefficient to the central zone node. The heat transfer coefficient includes both convective and radiative heat transfer. In some circumstances the central node temperature may differ significantly from the true "air"

temperature. Nevertheless, with proper calculation of the combined zone surface coefficients, the resulting error is comparable to that produced by differences in radiation transfer resulting from the detailed modeling of furniture in the zone. The central zone temperature T could be referred to as zone "air" temperature. Ventilation rates are set separately for each zone as calculated from the nodal ventilation model, where pressure zones are identical to the thermal model zones. No vertical stratification of flows is implemented in the thermal model. For each 1h time step new node temperatures are calculated for each mass wall defined.

The energy balance equation defining the zone air temperature, T, can be expressed as:

$Qwall + Qzone + Qwindow + Qamb + Qgrd + Qinf + Qsolzon + Qappli + Qfan + Qheat - Qvent - Q cool = 0$ (17)

Where:

$Qwall$ = energy flow between zone and enclosing mass walls;

$Qzone$ = energy flow between zones through explicitly defined interzone loss coefficients or through massless walls between zones;

$Qwindow$ = energy flow through windows;

$Qamp$ = energy flow to ambient air through explicitly defined loss coefficients to ambient or through massless walls between zone and ambient;

$Qgrd$ = energy flow to user-specified "ground" node through explicitly defined loss coefficients to ground or through massless walls between zone and ground;

$Qinf$ = energy flow due to air infiltration and ventilation;

$Qsolzon$ = total solar heat gain to zone;

$Qappli$ = user-defined appliance gain;

$Qfan$ = energy flow between zones by fans;

$Qheat$ = heating energy supplied to zone;

$Qvent$ = energy removed from zone by venting;

$Qcool$ = energy removed from zone by cooling.

The above equation is simplified by removing the addendums referring to special passive solar systems, which are not included in the building under examination.

The thermal network model contains only nodes with heat capacity in the interior of the wall. The governing equation for these internal nodes is derived from an instantaneous heat balance on the node. The rate of heat storage equals the rate of heat gain from the node to the left, plus the rate of heat gain from the node on the right. It is expressed mathematically as follows:

$$C \cdot \frac{dT}{dt} = HL \cdot (TL - T) + HR \cdot (TR - T) \quad (18)$$

where:

T	=	middle node temperature.
TL	=	left node temperature.
TR	=	right node temperature.
HL	=	thermal conductance to left node.
HR	=	thermal conductance to right node.
C	=	thermal capacitance of middle node.
$\frac{dT}{dt}$	=	time derivative of middle node temperature.

The differential equations (one for each node) are solved by using explicit finite differences or Euler integration. The new temperature at the end of a time step is approximated as:

$$T' = T + D \cdot \left(\frac{dT}{dt} \right) \quad (19)$$

where:

T'	=	new node temperature at the end of time step
T	=	old node temperature
D	=	length of time step (1 h).

The results in a set of independent equations for the new node temperatures, each of which have the form:

$$T' = \left(1 - D \cdot \frac{HL}{C} - D \cdot \frac{HR}{C} \right) \cdot T + D \cdot \frac{HL}{C} \cdot TL + D \frac{HR}{C} \cdot TR \quad (20)$$

The second law of thermodynamics, as well as the mathematical stability of explicit solution, requires that the first term in parenthesis should not be negative.

Energy flow, *Qinf,* due to infiltration and ventilation is calculated as follows:

$Qinf = UAinf \cdot (Tamb - T)$ (21)

Where:

$Tamb$	=	Ambient air temperature.
T	=	zone air temperature.
$Uainf$	=	infiltration equivalent conductance value.

Where:

$UAinf = vol \cdot Cair \cdot Pair \cdot e^{a \cdot elev} \cdot ACH$ (22)

Where:

vol	=	zone air volume in m^3.
Cair	=	air specific heat = 1.00418 KJ / kg·C.
Pair	=	air density at sea level = 1.20138 kg/m^3.

elev = station elevation in m.

a = coefficient derived from exponential curve fit = $-1.219755 \cdot 10^{-4}$ / m.

ACH = infiltration and ventilation air change rate in h^{-1}.

7. Combined thermal and ventilation modelling

Two basic cases of the coupling of a thermal model with a ventilation model may be distinguished:

- The zone temperatures are first calculated by the thermal model using predefined ventilation rates as inputs and then the zone flows are recalculated by the ventilation model using the calculated temperatures as inputs.

- The flows are first calculated by the ventilation model using predefined temperatures as inputs and then the zone temperatures are recalculated by the thermal model using the calculated flows as inputs.

Thermodynamic balance needs to be established in either case of coupling, whether the temperatures are different in the two models (2nd case), or the ventilation flows are different (1st case). In this work the thermal model (COMIS) and the ventilation model (Suncode) are two autonomous programs that are executed sequentially at 1h time-step (sequential coupling). There are, therefore, individual input and output files for the interconnection of the models, so the sequential coupling occurs at each time step. The coupling procedure implemented is presented in Fig. 2 and 3.

If the procedure is not implemented carefully, sequential coupling could affect the thermodynamic integrity of the system and therefore the zone temperatures and the thermal flows through building elements could be erroneous. The coupling was checked and validated, performing real case measurements, as described in the next paragraph.
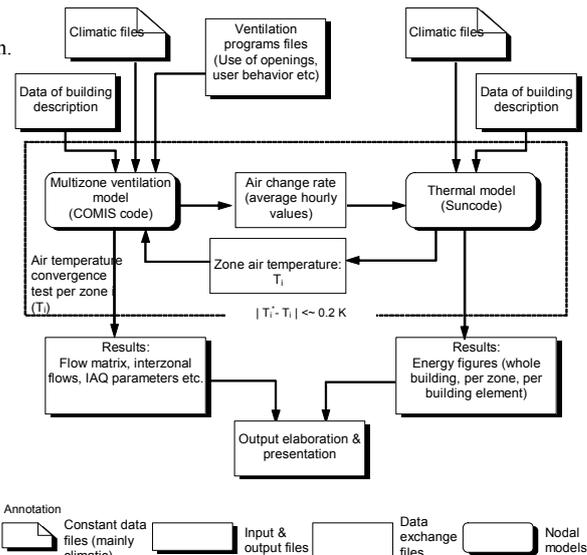
Figure 19: The introduced procedure of thermal and infiltration coupling.

The integrity of the final results depends greatly on the pattern of changes in the boundary conditions and on the simulation time step. The solution of the nodal network model is based on mass balance as follows: during each time step, the mass transport problem is simulated by a steady flow of incompressible fluid (air), through the flow links (cracks or large openings) which form the flow path network of the building. The steady flow mentioned above could be unidirectional, bidirectional, or a flow through cracks, depending on the ventilation phenomena (single-sided or cross ventilation, infiltration, flow through ducts), implementing the appropriate model in each case. This network operates under certain boundary conditions, defined from climatic data, wind pressures on the building's envelope, as well as temperatures and thermal flows of building elements. The problem therefore focuses on calculating the mass flows through flow links which connect the nodes (zones) of the network that stand for the zone pressures, which are the unknown quantities of the problem. The solution is achieved by implementing an iteration method for mass balance equations and the unknown nodal pressures are iteratively approximated.

Each node has a specific reference height and a specific air temperature, depending on the boundary conditions in the zone. The reference height and the temperature are then used for calculating the flows due to buoyancy (stack effect), which are of great importance.

The flow chart in Fig. 3 shows that in the case of sequential coupling during a time step, air flows (in fact mass flows) are calculated on the assumption that the air temperature is uniform of

each zone (T_i^*) in the previous time step. During the first passage of a specific time step the zone air temperature equals T_i^*, where i is the variable that defines the number of iterations performed in the specific time step. Therefore, in each iteration the relation $(T_i^* + T_i)/2$ is used which means sequential replacements with a relaxation factor 0.5.
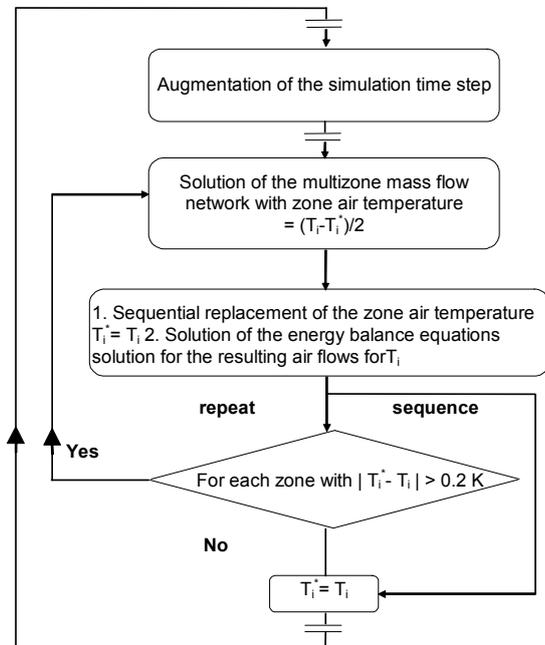
Figure 20: Flow chart of sequential coupling procedure.

8. General Conclusion

One comes to the conclusion that a planner should not base his/her decisions exclusively on the A/V ratio, but also consider all other parameters that could affect the energy behaviour of the building to be.

As shown, there are many tools for a planner to easier his/her work. But as important it is to know them, it is also of high importance to know how to use them. A planner should not only consider the optimal energy behaviour of a building, but also consider its future use and the needs of its users. For example, let us go back to the 2nd case. If we are to build a housing unit, according to the results of this case, it should be a big block instead of a row of detached single-family houses. Obviously, this is a false way of thinking. A planner should always take into account the different qualities, the future users and of course the urban planning.

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